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CLAIMS

1. A capacitive motion encoder for sensing the position of a moving object relative to a stationary object, comprising:

at least one stationary element, coupled to the stationary object;

a moving element, coupled to the moving object and in proximity to the stationary element;

a field transmitter, which generates an electrostatic field, which is modulated by a change in capacitance between the stationary and moving elements responsive to relative motion of the elements;

a conductive shield, which is electrically decoupled from both the moving and the stationary objects, and which encloses the moving and stationary elements so as to shield the elements from external electrical interference; and

processing circuitry, coupled to sense the modulated electrostatic field and to determine responsive thereto a measure of the position of the moving object.

2. An encoder according to claim 1, wherein the moving element comprises a rotor, and the moving object comprises a rotating shaft, and wherein the at least one stationary element comprises at least one stator, such that the processing circuitry determines a measure of the rotational position of the shaft.

3. An encoder according to claim 2, wherein the conductive shield encloses at least a portion of the processing circuitry together with the rotor and the at least one stator.

4. An encoder according to claim 3, wherein the at least one stator and the rotor comprise printed circuit boards, on at least one of which at least the portion of the processing circuitry is mounted.

5. An encoder according to claim 2, wherein the rotor comprises a generally planar plate and a substantially non-planar, annular hub for coupling the rotor to the shaft, and wherein the shield extends into the plane of the rotor adjacent to the hub so as to prevent electrical interference from passing from the shaft to the rotor.

6. An encoder according to claim 2, wherein the encoder is configured so that the rotor can rotate by at least 360^{o} relative to the stator.

7. An encoder according to claim 1, and comprising a mechanical housing around the moving and stationary elements, which housing is electrically decoupled from the shield.

8. An encoder according to claim 7, wherein the at least one stationary element comprises two generally parallel, mutually spaced stationary elements, one including the field transmitter and the other including a field receiver, which are electrically coupled one to the other in the housing by pressure of the elements against a flexible conductive member therebetween.

9. An encoder according to claim 1, wherein the stationary element comprises a printed circuit board including an extension which protrudes through the shield, to which an electrical connection is made to the encoder.

10. An encoder according to claim 1, wherein the field transmitter is attached to the stationary element and is coupled so as to form a part of the conductive shield.

11. An encoder according to claim 1, wherein the field transmitter is attached to the stationary element, and wherein the moving element has an electrically-active pattern thereon, which modulates the electrostatic field.

12. An encoder according to claim 11, wherein the electrically-active pattern comprises a dielectric material.

13. An encoder according to claim 11, wherein the electrically-active pattern comprises a conductive material.

14. An encoder according to claim 13, wherein the conductive material is coupled to the processing circuitry and serves as a receiver of the electrostatic field.

15. An encoder according to claim 13, wherein the at least one stationary element comprises a receiver of the electrostatic field, which is coupled to the processing circuitry.

16. An encoder according to claim 15, wherein the conductive, electrically-active pattern on the moving element is held at a generally constant potential.

17. An encoder according to claim 15, wherein the conductive, electrically-active pattern on the moving element is electrically floating.

18. An encoder according to claim 15, wherein the at least one stationary element comprises a single element to which both the transmitter and receiver are attached.

19. An encoder according to claim 16, and comprising a second stationary element having both a transmitter and receiver attached thereto.

20. A capacitive angle encoder for sensing position of a rotating shaft, comprising:

a transmitter, comprising multiple segments disposed about the shaft, each segment generating a periodic electrostatic field at a common frequency, but having a different, predetermined phase from the other segments;

a receiver, which generates signals responsive to the fields from the multiple segments such that the

strength of reception of each of the fields is modulated by a variation of a capacitance between the transmitter and the receiver, as a function of rotation of the shaft; and

a detector circuit including at least one synchronous detector, which processes the signals in synchronization with the generated field so as to generate an output indicative of the rotation angle.

21. An encoder according to claim 20, wherein the at least one synchronous detector comprises two synchronous detectors, which generate respective outputs proportional to the sine and cosine of the rotation angle.

22. An encoder according to claim 20, wherein the receiver comprises a single input amplification channel through which the signals from all of the transmitter segments are received for processing.

23. An encoder according to claim 20, wherein the transmitter plate comprises a generally planar transmitting stator, divided into multiple segments disposed around an axis of the shaft.

24. An encoder according to claim 23, wherein the multiple segments are arranged in four quadrants.

25. An encoder according to claim 23, wherein the receiver comprises a generally planar rotor, having a receiving area which has a rotational asymmetry about the axis of the shaft, and which rotates with the shaft adjacent to the stator.

26. An encoder according to claim 25, wherein the receiving area has a generally circular shape, which is eccentric about the axis of the shaft.

27. An encoder according to claim 23, wherein the receiver comprises a generally planar receiving stator, and comprising a generally planar rotor, having an electrically active area which has a rotational asymmetry

about the axis of the shaft, and which rotates with the shaft and modulates the received signals.

28. An encoder according to claim 27, wherein the electrically active area of the rotor has a generally circular shape, which is eccentric about the axis of the shaft.

29. A capacitive angle resolver for sensing position of a rotating shaft, comprising:

a transmitter, which generates a periodic electrostatic field responsive to an AC electrical input at a given frequency;

a receiver, comprising multiple segments disposed about the shaft, which generate signals responsive to the field from the transmitter such that the field received at each of the segments is modulated by a variation of a capacitance between the transmitter and the receiver as a function of rotation of the shaft;

a signal processing circuit, which processes the signals from the receiver segments so as to generate an AC output indicative of the rotation angle; and

a rectifier circuit, which rectifies the AC input so as to provide DC voltage to the detector circuit.

30. An encoder according to claim 29, wherein the signal processing circuit processes the signals in synchronization with the generated field, and wherein the AC output comprises two outputs respectively proportional to the sine and cosine of the rotation angle.

31. An encoder according to claim 29, and comprising a rotor coupled to rotate with the shaft and having an electrically active pattern thereon, such that rotation of the rotor modulates the field received at the receiver.

32. An encoder according to claim 31, wherein the electrically active pattern comprises conductive material.

33. An encoder according to claim 32, wherein the conductive material is held at a ground potential.

34. A capacitive motion encoder for sensing the position of a moving object relative to a stationary object, comprising:

at least one stationary element, coupled to the stationary object;

a moving element, coupled to the moving object and in proximity to the stationary element;

an electrostatic field transmitter, associated with one of the stationary or moving elements;

a field modulator associated with another of the stationary and moving elements, comprising smoothly-varying coarse and fine periodic electrically-active patterns on the element, the patterns varying along a dimension of the element with respective low and high spatial frequencies, which modulate the electrostatic field by inducing a variation in capacitance between the stationary and moving elements responsive to relative motion of the elements, at modulation frequencies corresponding to the low and high spatial frequencies, substantially without spatial harmonics thereof; and

processing circuitry, coupled to sense the modulated electrostatic field and to determine responsive thereto coarse and fine measures of the position of the moving object.

35. An encoder according to claim 34, wherein the moving element comprises a rotor, and the moving object comprises a rotating shaft, and wherein the stationary element comprises a stator, such that the processing circuitry determines a measure of the rotational position of the shaft.

36. An encoder according to claim 35, wherein the stator comprises a single planar element including a plurality

of conductive areas, at least one of which is the field transmitter, and another of which receives the field.

37. An encoder according to claim 35, wherein the electrically-active patterns are formed on the rotor such that the coarse periodic pattern comprises a generally circular area on the rotor, disposed eccentrically about the shaft, and wherein the fine periodic pattern comprises a sinusoidal pattern on the rotor, disposed circumferentially around the shaft.

38. An encoder according to claim 37, wherein the generally circular area of the coarse pattern is divided into a plurality of sub-areas, distributed over a surface of the rotor so as to reduce variations arising in the modulation of the field due to tilt of the rotor relative to the stator.

39. An encoder according to claim 34, wherein the field modulator further comprises an intermediate electrically active pattern thereon, having a spatial frequency intermediate the high and low frequencies, and wherein the processing circuitry senses modulation of the field corresponding to the intermediate frequency.

40. A capacitive motion encoder for sensing the position of a moving object relative to a stationary object, comprising:

at least one stationary element, coupled to the stationary object;

a moving element, coupled to the moving object and in proximity to the stationary element;

an electrostatic field transmitter, associated with one of the stationary or moving elements;

a field modulator associated with another of the stationary and moving elements, comprising coarse and fine, periodic, electrically-active patterns on the element, the patterns varying along a dimension of the element with respective low and high spatial frequencies,

which modulate the electrostatic field by inducing a variation in capacitance between the stationary and moving elements responsive to relative motion of the elements, at modulation frequencies corresponding to the low and high spatial frequencies; and

processing circuitry, which switches the electrostatic field so that it is modulated alternately by the coarse or by the fine pattern, and which senses the modulated field so as to alternately determine, responsive thereto, coarse and fine measures of the position of the moving object.

41. An encoder according to claim 40, wherein the moving element comprises a rotor, and the moving object comprises a rotating shaft, and wherein the at least one stationary element comprises a stator, such that the processing circuitry determines a measure of the rotational position of the shaft.

42. A capacitive motion encoder for sensing the position of a moving object relative to a stationary object, comprising:

a stationary element, coupled to the stationary object, and including an electrostatic field transmitter and receiver;

a moving element, coupled to the moving object and in proximity to the stationary element, and including a field modulator comprising coarse and fine periodic electrically-active patterns on the moving element, which vary along a dimension of the element with respective low and high spatial frequencies, and which modulate the electrostatic field by inducing a variation in capacitance between the stationary and moving elements responsive to relative motion of the elements, at modulation frequencies corresponding to the low and high spatial frequencies; and

processing circuitry, coupled to sense the modulated electrostatic field and to determine responsive thereto coarse and fine measures of the position of the moving object.

43. An encoder according to claim 42, wherein the moving element comprises a rotor, and the moving object comprises a rotating shaft, and wherein the stationary element comprises a stator including a plurality of conductive areas, at least one of which is the field transmitter and another of which is the receiver, such that the processing circuitry determines a measure of the rotational position of the shaft.

44. A capacitive angle encoder for sensing the position of a rotating shaft, comprising:

one or more stators, one of which comprises a field transmitter which generates an electrostatic field;

a rotor, coupled to rotate with the shaft, and having a rotationally-asymmetric electrically-active pattern thereon which modulates the electrostatic field responsive to rotation of the shaft by inducing a variation in capacitance between the stator and the rotor that repeats once for each rotation of the shaft, wherein the pattern is divided into a plurality of sub-areas so as to reduce variations arising in the modulation of the field due to tilt of the rotor relative to the stator; and

processing circuitry, coupled to sense the modulated electrostatic field and to determine, responsive to the coarse and fine variations, coarse and fine measures of the angle of the shaft.

45. An encoder according to claim 44, wherein the electrically-active pattern on the rotor comprises a generally circular area located eccentrically relative to an axis of the shaft.

46. A capacitive angle encoder for sensing position of a rotating shaft, comprising:

a rotor, coupled to the shaft, having an electrically-active region which has a rotational asymmetry about an axis of the shaft and includes a pattern disposed circumferentially on the rotor which repeats multiple times about the shaft at a predetermined angular frequency;

at least one stator, having an electrostatic field associated therewith, which is modulated due to a variation in capacitance induced by the electrically active region due to rotation of the rotor; and

processing circuitry, which senses modulation of the field occurring once per rotation of the shaft due to the rotational asymmetry of the region so as to determine, responsive thereto, a coarse measure of the rotation angle of the shaft, and which senses modulation of the field due to the pattern so as to determine a fine measure of the rotation angle.

47. An encoder according to claim 46, wherein the electrically-active region comprises a generally circular region, which is eccentric relative to the shaft axis.

48. An encoder according to claim 46, and comprising a receiver coupled to one of the one or more stators and characterized by a rotational asymmetry relative to the shaft axis such that the coarse measure of the angle is determined responsive to an interaction between the non-axisymmetries of the fine pattern and the receiver.

49. An encoder according to claim 46, and comprising a switch, which is actuated to determine alternately the coarse and fine measures of the angle.

50. An encoder according to claim 49, wherein the stator comprises multiple conductive sectors, each coupled to the processing circuitry, which groups signals received from the sectors responsive to actuation of the switch so

as to alternately determine the coarse and fine angle measures.

51. A moisture-resistant capacitive motion encoder for sensing the position of a moving object relative to a stationary object, comprising:

at least one stationary element, coupled to the stationary object, and having an electrostatic field associated therewith;

a moving element, coupled to the moving object, comprising a plurality of electrically active segments mutually separated by spaces, the segments forming a pattern that modulates the electrostatic field due to a variation in capacitance between the stationary and moving elements as the moving element moves; and

processing circuitry, coupled to sense the modulated electrostatic field and to determine responsive thereto a measure of the position of the moving object.

52. An encoder according to claim 51, wherein fluid impinging on the moving element is displaced from the segments to the spaces separating the segments.

53. An encoder according to claim 51, wherein the moving object comprises a rotating shaft, and the moving element comprises a rotor from which the electrically active segments protrude radially outward around the shaft, and wherein the at least one stationary element comprises at least one stator, such that the processing circuitry determines a measure of the rotational position of the shaft.

54. A capacitive motion encoder for sensing the position of a moving object relative to a stationary object, comprising:

a moving element, coupled to the moving object, having an electrically-active pattern thereon;

first and second stationary elements, coupled to the stationary object, disposed on opposing sides of the

moving element so as to transmit an alternating electrostatic field therethrough;

processing circuitry, coupled to sense modulation of the electrostatic field responsive to a variation in capacitance between the stationary elements due to movement of the electrically-active pattern therein and to determine responsive thereto a measure of the position of the moving object; and

a potential stabilization circuit, which maintains the moving element at a generally constant potential by sensing an alternating electrical potential at the first stationary element and applying an opposite potential to the second stationary element.

55. An encoder according to claim 54, wherein the generally constant potential comprises a virtual ground.

56. An encoder according to claim 54, wherein the potential stabilization circuit makes substantially no electrical contact with the moving element.

57. An encoder according to claim 54, wherein the moving object comprises a rotating shaft, and the moving element comprises a rotor coupled to the shaft, and wherein the first and second stationary elements comprise a pair of stators, such that the processing circuitry determines a measure of the rotational position of the shaft.

58. A capacitive linear displacement encoder, for sensing the position of a moving object relative to a stationary object, comprising:

a ruler, fixed to the stationary object;

a reading head, fixed to the moving object so as to move along the ruler, and comprising an electrostatic field transmitter, which generates an electrostatic field in a vicinity of the reading head;

an electrically-active pattern formed on the ruler, which pattern causes a variation in capacitance between the ruler and reading head so as to modulate the

electrostatic field responsive to motion of the reading head relative to the ruler, the pattern having a symmetry such that the modulation is substantially unaffected by tilt of the head relative to the ruler; and

processing circuitry, coupled to sense the modulated electrostatic field, so as to detect the modulation and determine responsive thereto a measure of the position of the moving object.

59. An encoder according to claim 58, wherein the pattern comprises a double sinusoid.

60. An encoder according to claim 58, wherein the reading head comprises a receiver, which receives the modulated electrostatic field, and wherein the pattern is intermittently broken by gaps in the pattern, so as to inhibit coupling of interference along the pattern into the reading head, wherein the gaps are formed at an acute angle relative to a longitudinal axis of the ruler.

61. A capacitive linear displacement encoder, for sensing the position of a moving object relative to a stationary object, comprising:

a ruler, fixed to the stationary object, and comprising an electrostatic field transmitter, which generates an electrostatic field in a vicinity of the ruler;

a reading head, fixed to the moving object so as to move along the ruler and having an electrically-active pattern formed thereon, which pattern causes a variation in capacitance between the ruler and reading head so as to modulate the electrostatic field responsive to motion of the reading head relative to the ruler, the pattern having a symmetry such that the modulation is substantially unaffected by tilt of the head relative to the ruler; and

processing circuitry, coupled to sense the modulated electrostatic field, so as to detect the modulation and

determines responsive thereto a measure of the position of the moving object.

62. An encoder according to claim 60, wherein the pattern comprises a double sinusoid.

63. A capacitive linear displacement encoder, for sensing the position of a moving object relative to a stationary object, comprising:

a ruler, fixed to a curved surface of the stationary object;

a reading head, fixed to the moving object so as to move along the ruler;

an electrostatic field transmitter, which generates an electrostatic field in a vicinity of the reading head;

an electrically-active pattern formed on the ruler or the reading head, which pattern causes a variation in capacitance between the ruler and the reading head so as to modulate the electrostatic field responsive to motion of the reading head relative to the ruler; and

processing circuitry, coupled to sense the modulated electrostatic field, so as to detect the modulation and determines responsive thereto a measure of the position of the moving object along the curved surface.

64. An encoder according to claim 63, wherein the stationary object has a generally cylindrical form, and wherein the measure of the position of the moving object comprises an angular measurement about an axis of the stationary object.

65. A capacitive linear displacement encoder, for sensing the position of a moving object relative to a stationary object, comprising:

a ruler, fixed to the stationary object;

a reading head, fixed to the moving object so as to move along the ruler;

transmitting plates fixed to the ruler, so as to generate and receive an electrostatic field in a vicinity

of the reading head, the plates having coarse and fine reading configurations;

an electrically-active receiving plate on the reading head, the plate configured such that motion of the head relative to the ruler causes a variation in capacitance between the transmitting and receiving plates, which modulates the electrostatic field received by the receiving plate; and

processing circuitry, coupled to sense the modulated electrostatic field, so as to detect the modulation of the field in the coarse reading configuration so as to determine responsive thereto a coarse measure of the position of the moving object, and to detect the modulation of the field in the fine reading configuration so as to determine responsive thereto a fine measure of the position of the moving object.

66. An encoder according to claim 65, wherein the coarse measure comprises an absolute position measurement.

67. An encoder according to claim 65, wherein the transmitting plate comprises a plurality of transmitting bars, which are collectively divided into at least two triangular regions, and wherein in the coarse configuration the bars in each of the regions are collectively excited.

68. An encoder according to claim 67, wherein the receiving plate comprises a conductive, periodic pattern superimposed on a generally quadrilateral region, and wherein when the transmitting plate is operating in the coarse reading configuration, the entire quadrilateral region is held at a common electrical potential.

69. A capacitive motion encoder for sensing the position of a moving object relative to a stationary object, comprising:

at least one stationary element, coupled to the stationary object;

a moving element, coupled to the moving object;

transmitting and receiving plates fixed to the stationary or the moving element, so as to generate and receive an electrostatic field in a vicinity of the moving element, the plates including at least one index plate at an index position on the stationary element, such that the electrostatic field encountered by the moving element while in proximity to the at least one index plate is identifiably different from that at other locations along the stationary element;

an electrically-active pattern formed on one of the elements, which pattern causes a variation in capacitance between the elements so as to modulate the electrostatic field responsive to motion of the moving element relative to the stationary element; and

processing circuitry, coupled to sense the modulated electrostatic field, and to identify the difference in the field when the moving element is in proximity to the index plate so as to determine responsive thereto that the moving element is in the index position, and which detects the modulation and determines responsive thereto a measure of the position of the moving object relative to the index position.

70. An encoder according to claim 69, wherein the stationary element comprises a linear ruler with the index plate at an end thereof, and wherein the moving element comprises a reading head which moves along the ruler.

71. A method for sensing position of a rotating shaft, comprising:

transmitting periodic electrostatic fields having a common frequency at a plurality of angular locations around the shaft, each field having a different, predetermined phase from the other signals;

sensing the fields from the plurality of locations, and generating signals responsive to modulation of the fields engendered due to a variation in capacitance as a function of rotation of the shaft; and

processing the signals in synchronization with the frequency of the transmitted fields so as to generate outputs indicative of the rotation angle.

72. A method according to claim 71, wherein processing the signals comprises generating outputs proportional to the sine and cosine of the rotation angle.

73. A method for sensing position of a rotating shaft, comprising:

receiving an AC electrical input at a given frequency;

generating a periodic electrostatic field responsive to the AC input;

rectifying a portion of the AC input so as to provide DC voltage to a detector circuit;

sensing the field at a plurality of locations, and generating signals responsive to modulation of the fields engendered due to a variation in capacitance as a function of rotation of the shaft; and

processing the signals using the detector circuit so as to generate an AC output at the given frequency indicative of the rotation angle.

74. A method according to claim 73, wherein processing the signals comprises generating outputs proportional to the sine and cosine of the rotation angle.

75. A method for sensing the position of a moving object relative to a stationary object, comprising:

transmitting an electrostatic field in a vicinity of the moving object;

associating smoothly-varying coarse and fine periodic electrically-active patterns with the moving object, the patterns varying along a dimension of motion

of the object with respective low and high spatial frequencies, which modulate the electrostatic field by inducing a variation in capacitance between the stationary and moving elements responsive to relative motion of the elements, at modulation frequencies corresponding to the low and high spatial frequencies, substantially without spatial harmonics thereof; and

sensing the modulated electrostatic field and to determine responsive thereto coarse and fine measures of the position of the moving object.

76. A method according to claim 75, wherein the moving object comprises a rotating shaft, and wherein associating the coarse pattern with the moving object comprises defining a generally circular area on a rotor, the area disposed eccentrically about the shaft.

77. A method for sensing the position of a moving object relative to a stationary object, comprising:

transmitting an electrostatic field in a vicinity of the moving object;

associating coarse and fine, periodic, electrically-active patterns with the moving object, the patterns varying along a dimension of motion of the object with respective low and high spatial frequencies, which modulate the electrostatic field by inducing a variation in capacitance between the stationary and moving elements responsive to relative motion of the elements, at modulation frequencies corresponding to the low and high spatial frequencies;

switching the electrostatic field so that it is modulated alternately by the coarse or by the fine pattern; and

sensing the modulated field so as to alternately determine, responsive thereto, coarse and fine measures of the position of the moving object.

78. A method for sensing position of a rotating shaft, comprising:

coupling to the shaft a rotor with an electrically-active region which has a rotational asymmetry relative to an axis of the shaft and comprises a pattern disposed circumferentially on the rotor, which pattern repeats multiple times about the shaft at a predetermined angular frequency;

transmitting an electrostatic field in a vicinity of the moving object;

sensing modulation of the field occurring once per rotation due to the non-axisymmetry of the region so as to determine, responsive thereto, a coarse measure of the rotation angle of the shaft; and

sensing modulation of the field due to the pattern so as to determine a fine measure of the rotation angle.

79. A method according to claim 78, wherein coupling the rotor comprises coupling a rotor with an electrically-active region characterized by a rotational asymmetry about the rotation axis of the shaft.

80. A method for sensing the position of a moving object relative to a stationary object, comprising:

coupling a moving element, having an electrically-active pattern thereon, to the moving object;

disposing first and second stationary elements on opposing sides of the moving element so as to transmit an electrostatic field therethrough;

sensing an electrical potential at the first stationary element and applying an opposite potential to the second stationary element so as to maintain the moving element at a generally constant potential; and

sensing modulation of the electrostatic field responsive to a variation in capacitance between the stationary elements due to movement of the electrically-

active pattern therein so as to determine responsive thereto a measure of the position of the moving object.

81. A method for sensing the position of a moving object relative to a curved surface, comprising:

fixing a reading head to the moving object;

fixing a flexible ruler along the curved surface;

providing an electrically-active pattern on the ruler or the reading head, which pattern causes a variation in capacitance between the ruler and the reading head so as to modulate the electrostatic field responsive to motion of the reading head relative to the ruler;

generating an electrostatic field in a vicinity of the reading head; and

sensing the modulated electrostatic field, so as to detect the modulation and determines responsive thereto a measure of the position of the moving object along the curved surface.